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Tillage system and cover crop effects on organic carbon and available nutrient contents in light chestnut soil

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Abstract

Optimal use of management systems including tillage and cover crops are recommended to improve available nutrient contents in soils and sustain agricultural production. The effects on organic carbon and available nutrient contents of three tillage methods (conventional tillage, minimum tillage and no-tillage) and different cover crops such as flaxseed oil, buckwheat, soybean, pea, corn, sorghum, spring oilseed rape and sugar beet were evaluated in a short-term experiment on a light chestnut soil in Kazakhstan. Organic carbon and available nutrient contents were measured in the autumn of 2021. The field measurements included the yield of cover crops and input of organic matter into soils with root and other residues of cover crops. In the laboratory, total organic carbon, labile organic carbon, easily hydrolyzable nitrogen (NH_4-N), NO_3-N, available P and exchangeable K were measured. The results showed that one season of cover crop growth was not enough to find detectable changes in soil organic matter and available nutrient status in light chestnut soils. On the other hand, even in a short-term field experiment period of 3 months, the most labile organic carbon in soil organic carbon was obtained in conventional tillage. Overall, the results show that at least in the short term and under lower drip irrigation rate in summer for the study area, reduced tillage methods (no-tillage and minimum tillage) is suitable in the study area for soybean, corn and sugar beet production after intensive tillage in the previous year.

Keywords: Cover crops, tillage, no-tillage, available nutrient, organic matter.

Introduction

The need for sustainable management strategies to maintain and improve soil health & quality, reducing problems such as land degradation & desertification and enhance agricultural production has been stressed by many studies in the light of an increasing world population and climate change (Komatsuzaki and Ohta, 2007; Lal, 2009; Abdollahi and Munkholm, 2014). In recent years, the concept of conservation agriculture has been promoted as an integrated management tool to meet the challenges of the future. The conservation agriculture concept includes increase soil organic matter, minimize tillage, rotate crops, plant and animal residue management, and cover crops as key elements (Farooq and Siddique, 2015; Jayaraman et al., 2021).

Currently, about 75% of the territories of Kazakhstan are subject to an increased risk of desertification, more than 30.5 million hectares are subject to soil erosion by wind and water, and 54% of these territories are located in the southern part of Kazakhstan (Turebayeva et al., 2022). In recent years, systemic measures have been taken in agriculture field in the Kazakhstan to apply highly efficient resource conserving technologies. No-tillage or reduced tillage were introduced in Kazakhstan as a system for soil protection which contributed to slow down soil erosion processes and increased the yield of crops (FAO, 2013: Saparov, 2014). Moreover, in different agricultural zones of the Kazakhstan, the basic principles of conservation agriculture has been

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developed by applying plant residues or animal wastes and No-tillage or Reduced tillage. Thus, no-tillage or reduced tillage are contributing to enhanced agricultural sustainability of dryland crops in semiarid areas by reducing erosion, and improving soil health & quality and soil ecosystem services (Suleimenova et al., 2019). Also, many studies have assessed the impact of the different conservation agriculture elements on soil health and quality, soil available nutrient contents, plant productivity individually in different ecological zone of Kazakhstan (Kurishbayev, 2003; Wall et al., 2007; Nurbekov et al., 2016), but no scientific studies have quantified the effect of different tillage practices combined with cover crops.

Cover crops are traditionally defined as crops grown to cover the ground to protect the soil from erosion and from loss of plant nutrients through leaching and runoff (Reeves, 1994) and these crops have been referred to as crops planted primarily to manage soil and water health, increase of biodiversity, limitation of pests, diseases, weeds, etc. (Lu et al., 2000; Scavo et al., 2022). Most cover crops are not grown solely for economic benefits, but for the ecosystem benefits they provide. Yunusa and Newton (2003) referred to cover crops as 'primer plants'; crops grown to condition the soil for the subsequent crops. Growing cover crops has been a popular practice in crop production throughout history (Reeves, 1994). They were originally grown as green manures, serving as a mulch and soil amendment, and were later incorporated into soil to improve fertility (Kasper and Singer, 2011) Also, cover crops can enhance soil health and quality through addition of organic matter when incorporated into the soil, helping to reduce compaction and increase infiltration; thus increasing available nutrient contents of soil and yield of plant (Dabney et al., 2001). We hypothesize that tillage and cover crop may significantly affect soil organic matter and available nutrient contents in the short term. The specific objective of this study was to assess the influence of different tillage practices combined with cover crops on total and labil organic matter, available nitrogen, phosphorus.

Material and Methods

Study Area

The experiment was performed at Agropark Kaskelen experimental-demonstration field of the Zailiyskiy Alatau, Kazakhstan (43°17'43.70 "N76°41'46.60 "E). This region is characterized by a semi-arid climate. The locations of the evaluations were characterized by the sharply continental climate (low cloud cover and a small amount of atmospheric precipitation, which fall mainly in the warm season), the air temperature reaches minimum values in January (-41^{0}C), and maximum values in July (+42^{0}C), the average annual temperature is +7.6 ^{0}C and an annual amount of precipitation is 414 mm.

Soil

A soil sample was collected from the experimental field at the beginning of the experiment. Physical and chemical properties of the experimental soil were determined Kazakh National Agrarian Research University according to the Rowell (1996) and Jones (2001). The main soil type is piedmont light chestnut soils. The soil had been developed from ormed on loess-like loams has a clearly pronounced fertile profile and contained 50% clay, 35% silt and 15% sand. The soil was characteristically slightly alkaline (pH 7.3-7.4), soil organic matter 2.02% (moderate), total N 0.12-0.14% (high), available phosphorus 23-25 mg kg^{-1} (low), exchangeable potassium 245-255 mg kg^{-1} (moderate).

Experimental design

In September 2020, winter wheat seeds (200 kg ha^{-1}) were planted on the 5 ha experimental land. With the sowing of the seeds, 100 kg ha^{-1} of ammonium phosphate (ammophos) fertilizer (11%N, 46%P_2O_5) was added to the soil. On 12 July 2021, the harvest of winter wheat in the field was carried out. At the end of the harvest, the wheat yield was determined as 5.66 t ha^{-1}. After the wheat harvest in the field, the land was divided into parcels and the experiment was established. The two factors (treatments) were three methods of tillage (no-tillage (NT), minimum tillage (MT) and conventional tillage (CT)) and eight types of cover crop (Flaxseed oil (FO), Buckwheat (BW), Soybean (SB), Pea (PE), Corn (CN), Sorghum (SM), Spring Oilseed Rape (OR) and Sugar beet (SB)). The field experiment field was a randomized complete block design on a 5 ha field arranged in a 3-factor factorial design with three replicates (a total of forty-eight plots). Each of the plots measured 34,5 m x 20 m (691 m^2). The experiment consisted of 72 parcels in total. The planting and harvesting dates of the rotation crops in the experiment and the agricultural practices are shown in the Table 1. All plants in the plots were harvested and yield and input of organic matter into soils with root and other residues of cover crops were converted to t ha^{-1}.

Table 1. The sowing and harvesting dates of the rotation crops in the experiment and the agricultural practices

Cover crops	Sowing date	Seed rate	Harvesting date	Drip irrigation rate
Flaxseed oil (FO)	12/07/2021	25 kg ha^{-1}	18/10/2021	400 m^3 ha^{-1}
Buckwheat (BW)	12/07/2021	32 kg ha^{-1}	18/10/2021	400 m^3 ha^{-1}
Soybean (SB)	12/07/2021	120 kg ha^{-1}	18/10/2021	600 m^3 ha^{-1}
Pea (PE)	12/07/2021	100 kg ha^{-1}	05/10/2021	600 m^3 ha^{-1}
Corn (CN)	14/07/2021	45 kg ha^{-1}	12/10/2021	800 m^3 ha^{-1}
Sorghum (SM)	12/07/2021	25 kg ha^{-1}	05/10/2021	600 m^3 ha^{-1}
Spring Oilseed Rape (OR)	12/07/2021	25 kg ha^{-1}	05/10/2021	400 m^3 ha^{-1}
Sugar beet (SB)	15/07/2021	2 kg ha^{-1}	18/10/2021	1000 m^3 ha^{-1}

100 kg Ammophos fertilizer (11%N, 46%P_2O_5) applied at sowing for all cover crops based on the recommendations of Kazakh Research Institute of Farming and Crop Production.

Soil Sampling and Analyses

After harvest, the soil samples collected from depth of 20 cm were naturally air-dried, milled and passed through 2.0 mm sieve. Total (TOC) and labile organic carbon (LOC) content by the titrimetric method using the biochromatic oxidation procedure by Tyurin-Kononova, Ammonia (easily hydrolyzable nitrogen) by the modified Kjeldahl method, nitrate by potantiometrically, available phosphorus was determined by Machigin method, exchangeable potassium content were determined by the 1N NH_4OAc extraction method according to the Tyurin, (1965), Rowell (1996) and Jones (2001).

Results and Discussion

The effects of different tillage methods on the yield of cover crops are given Table 2. It has been determined that different tillage methods have a significant effect on the yields of the cover crop. According to the results obtained; While the highest yield results were obtained in FO, BW, PE, SM, OR cultivation with CT, it was determined that the highest yield was obtained in CN and SB cultivation with MT, and in SB cultivation with NT. In this experiment, as in the short-term effects, it is thought that the absence of plant residue on the soil surface in the cultivation of cover crops, NT and MT conditions cause poor plant growth compared to CT. Therefore, it has been determined that NT and MT are not suitable for many plants (FO, BW, PE, SM and OR) in conditions where there is no cover layer consisting of plant residues on the soil surface, considering only the crop yield. Because the benefits of NT or MT are due to this cover (mulch) layer formed on the soil. Compared to the CT system, the advantage of the NT and MT systems are not the fact that the soil is not cultivated, but the presence of plant residues on the soil surface.

Table 2. The effect of different tillage methods on the yield of cover crops (t ha^{-1})

Cover Crops	Tillage methods		
	Conventional tillage (CT)	Minimum tillage (MT)	No-tillage (NT)
Flaxseed oil (FO)	1,01 ± 0,04	0,99 ± 0,03	0,89 ± 0,03
Buckwheat (BW)	1,53 ± 0,06	1,33 ± 0,04	1,12 ± 0,04
Soybean (SB) †	14,58 ± 0,50	13,32 ± 0,56	16,76 ± 1,09
Pea (PE) †	9,90 ± 0,44	8,52 ± 0,43	7,26 ± 0,37
Corn (CN) †	19,44 ± 0,91	19,99 ± 0,84	15,90 ± 0,76
Sorghum (SM) †	23,06 ± 1,06	17,33 ± 0,74	12,20 ± 0,68
Spring Oilseed Rape (OR) †	23,34 ± 0,82	13,85 ± 0,58	5,44 ± 0,17
Sugar beet (SB)	7,88 ± 0,35	10,60 ± 0,55	6,98 ± 0,36

† Green mass of cover crop

Input of organic matter into soils with root and other residues of cover crops with different methods of tillage are given Table 3. Contrary to the yield results of the cover crops, it was determined that the amount of organic matter (mulch) added to the soil by the cover crops differed according to the tillage methods. In the case of CN and SB plants grown as cover crops, the highest organic matter input was determined in CT, while the maximum in FO, BW, SB, OR cultivation was determined in MT, and in NT in PE, SM cultivation. With CT, the development of weeds in the soil is limited. In the experiment, weed control was not done with the weeds formed in the plots with cover crops by using any chemicals (herbicides). Therefore, the reason for the increase in the amount of organic matter added to the soil under MT and NT conditions in the experiment may have been caused by weeds that were not controlled.

Table 3. Input of organic matter into light chestnut soils with root and other residues of cover crops with different tillage methods (t ha^{-1})

Cover Crops	Tillage methods		
	Conventional tillage (CT)	Minimum tillage (MT)	No-tillage (NT)
Flaxseed oil (FO)	1,52	2,00	1,27
Buckwheat (BW)	1,25	0,40	0,82
Soybean (SB)	1,90	2,12	1,60
Pea (PE)	0,66	0,52	0,67
Corn (CN)	7,97	7,62	7,80
Sorghum (SM)	2,40	2,52	2,95
Spring Oilseed Rape (OR)	3,50	3,72	3,12
Sugar beet (SB)	0,60	0,27	0,25

The total organic carbon (TOC) and labile organic carbon (LOC) contents of the light chestnut soil samples taken at the end of the harvest from the plots where different cover crops were grown are given in Table 4. According to the results obtained, it was determined that different tillage methods affected the TOC and LOC contents of the soils of the plots where different cover crops were grown at different rates. LOC is a component of TOC. While LOC constitutes 11.05% of the TOC as the average of all plots in CT, this rate is determined as 9.54% in MT and 7.86% in NT. In CT methods, the mineralization rate of organic matter, the amount of LOC and the amount of CO_2 production as a result of mineralization of organic C increase as the soil is cultivated frequently and the aeration capacity of the soil increases. Soils that have been degraded through excessive tillage tend to have less SOM due to an increased amount of exposed surface area, which facilitates aerobic decomposition (DeBusk et al., 2001). Carbon makes up more than half the mass of SOM (Montgomery et al., 2000), and it has been shown that cultivating the land influences the dynamics of SOC and, in turn, the amount of C emitted from the soil as CO_2 due to the oxidation or decomposition of SOM (Paustian et al, 1995; Reicosky et al., 1995).

Table 4. Changes in the total organic carbon (TOC) and labile organic carbon (LOC) contents of light chestnut soils with different tillage methods and cover crops.

Cover Crops	Tillage methods					
	Conventional tillage (CT)		Minimum tillage (MT)		No-tillage (NT)	
	TOC, %	LOC, mg kg^{-1}	TOC, %	LOC, mg kg^{-1}	TOC, %	LOC, mg kg^{-1}
Flaxseed oil (FO)	0,78	940	0,83	920	1,03	690
Buckwheat (BW)	0,88	1190	1,03	820	0,94	780
Soybean (SB)	1,05	1070	0,88	820	0,94	800
Pea (PE)	1,01	1070	0,83	690	1,03	820
Corn (CN)	1,00	1070	1,05	940	0,91	570
Sorghum (SM)	1,12	1070	0,94	920	0,85	690
Spring Oilseed Rape (OR)	0,88	940	0,88	840	0,88	780
Sugar beet (SB)	1,03	1190	1,05	1190	0,83	680

In order to determine the effects of different tillage methods and cover crops on the available amounts of nitrogen, phosphorus and potassium in the soil, the results obtained from the light chestnut samples taken at the end of the harvest in this experiment are given in Table 5. According to the results obtained from the experiment, it was determined that there were significant differences in the amount of available nutrients according to the type of cover crops and tillage methods. Considering the average data of the plots where different cover crops were grown, it was determined that CT increased the most NH_4-N and exchangeable potassium content in the soil, while MT increased the NO_3-N content of the soil and NT increased the available phosphorus content. The reason for the high NH_4-N content in CT is probably related to soil organic matter and its mineralization. Soil organic matter is made up of approximately 5% N, which is mineralized into ammonium (NH_4^+) during the decomposition process. Mineralized N is susceptible to removal from or translocation within the soil after nitrification through the leaching of nitrate (NO_3^-) and through gaseous losses during denitrification (Havlin et al., 2013).

This study did not reveal very significant results on the effects of different cover crops and tillage methods on the available nutrient content of light chestnut soils. In addition, it is very difficult to say that any tillage method or cover crop comes to the fore with the results obtained. Possible reasons could be: 1) the field experiment in this study is that only 3 months have passed between the sowing and harvesting dates of the cover crops; 2) the organic matter entry into the soil from the cover crops has not yet been achieved. Similarly, Chan and

Heenan (1996) and Jokela et al. (2009) suggested that soil quality indicators like the ones used in this study might only be detectable after more than four years of continuous cover crop growth.

Table 5. Changes in mineral N (NH_4-N and NO_3-N), available P and exchangeable K contents of light chestnut soils with different tillage methods and cover crops.

Cover Crops	NH_4-N, mg kg^{-1}			NO_3-N, mg kg^{-1}			Available P, mg kg^{-1}			Exchangeable K, mg kg^{-1}		
	CT	MT	NT	CT	MT	NT	CT	MT	NT	CT	MT	NT
Flaxseed oil (FO)	56	47	56	61	45	60	19	35	60	230	200	294
Buckwheat (BW)	81	56	81	38	44	44	19	56	40	230	283	373
Soybean (SB)	63	60	60	40	42	39	25	46	57	456	210	327
Pea (PE)	63	49	77	36	43	45	35	28	57	408	262	230
Corn (CN)	61	85	56	40	57	46	24	28	19	350	339	272
Sorghum (SM)	71	70	61	39	91	45	24	61	29	373	361	241
Spring Oilseed Rape (OR)	106	96	51	51	46	51	51	31	47	350	272	251
Sugar beet (SB)	79	51	65	42	53	51	30	30	37	350	283	230

Conclusion

This short-term field experiment shows that one season of cover crop growth was not enough to find detectable changes in soil organic matter and available nutrient status in light chestnut soils. On the other hand, even in a short-term field experiment period of 3 months, the most labile organic carbon in soil total organic carbon was obtained in conventional tillage. This is a clear evidence that as a result of conventional tillage, organic matter will be rapidly broken down and its amount in the soil will decrease. Overall, the results show that at least in the short term and under lower drip irrigation rate in summer (for the study area), No-tillage and minimum tillage is suitable in the study area for soybean, corn and sugar beet production after intensive tillage in the previous year. Moreover, there is no doubt that a significant amount of organic matter will enter the soil as a result of the cover crop harvest. Therefore, the long-term effects of cover crops and different tillage methods need to be determined by field experiment.

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